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***Abstract*—We report the latest performance of an ultrafast, all-optical beam deflector based on a prism array imprinted in a planar waveguide. The deflector enables single-shot, high dynamic range optical recording with picosecond resolution.**

I. Introduction

Deflection of optical beams at picosecond timescales enables novel approaches to many technologies, including: ultrafast measurement of optical transients, optical time division multiplexing (OTDM)[1], and generation of arbitrarily shaped ultrashort pulses [2]. Various deflection methods have implemented elecro-optic effects [1], soliton-steering [3], and Kerr-induced prisms [4], [5]. Here, we demonstrate a novel, ultrafast optical beam deflector distinguished by an extremely simple architecture. Deflection takes place at picosecond timescales. We call our technique Serrated Light Illumination for Deflection Encoded Recording (SLIDER). An ultrafast, single-shot optical recording system based on the SLIDER device is capable of high dynamic range measurements at picosecond temporal resolutions.

II. Device Concept

An ultrafast recording system using SLIDER is shown in Fig. 1. A signal beam is injected into a slab waveguide until the temporal region of interest is fully contained. At this time, a normally-incident pump beam patterned by a serrated mask imprints a sequence of prisms in the waveguide core. The imprinting is achieved via carrier-based optical nonlinearities that turn on rapidly and remain latched (due to slow recovery) for the duration of the sweep. Because earlier portions of the signal encounter fewer prisms, the signal beam deflects in linear proportion to the time delay across the signal. The deflected beam exiting the waveguide is focused onto a camera that records the amplitude in each time bin. The concept is analogous to a streak camera, in which the conventional electron beam is replaced by a photon beam. This avoids undesirable space-charge effects that couple temporal resolution and dynamic range.

III. Fundamental Limitations on Temporal Record Length and Resolution

The record length (T) of a recording system based on SLIDER is given by the time of flight through a pumped region of length Z: $T = Z/v_g$, where v_g is the signal group velocity. The number of resolvable spots is equal to the ratio of the maximum deflection angle θ to the angular resolvability $\delta\theta$. For small angles, θ is given by the number of prisms (N_p) multiplied by the deflection per prism: $\theta = N_p \kappa \Delta\bar{n}$, where $\Delta\bar{n}$ is the change in effective index and κ the wedge angle. For a lateral prism width X, $N_p \approx Z/(X\kappa)$, resulting in a deflection of $\theta = \Delta\bar{n} Z/X$. The angular resolvability is given by: $\delta\theta \approx \lambda/X$. Therefore, the number of resolvable spots $N = \theta/\Delta\theta \approx \Delta\bar{n} Z/\lambda$. Dividing T by N yields a temporal resolution of $\tau = \lambda/(v_g \Delta\bar{n})$.

In GaAs at a wavelength of 950 nm, 1 ps resolution requires $\Delta\bar{n} \approx 0.01$. Semiconductor carrier-based optical non-linearities can achieve such changes with picosecond rise times, but are typically overlooked for ultrafast applications due to nanosecond recovery times. Here, the long recovery time ensures that the refractive index of the induced prisms remains constant for the duration of the beam sweep.

Temporal resolution may be further limited by: 1) prism array discretization, 2) prism fidelity in the presence of pump diffraction and carrier diffusion, 3) material dispersion (static and induced), and 4) pump beam nonuniformity. It is important to mitigate all of these effects when pursuing temporal resolutions approaching 1 ps. A longitudinal prism spacing $<$ 100 μm allows for a temporal resolution $<$ 0.5 ps. Diffraction of the prism pattern is negligible for cladding thickness $<$ 10 μm, and assuming a diffusion coefficient of 20 cm^2/s for GaAs, carrier diffusion effects are insignificant for sweep duration $<$ 1 ns. Temporal blurring due to group velocity dispersion (GVD) becomes significant for temporal resolutions approaching 1 ps. Dispersion in the induced index change also leads to temporal blurring of the measured signal, since different spectral components are deflected to different angles.

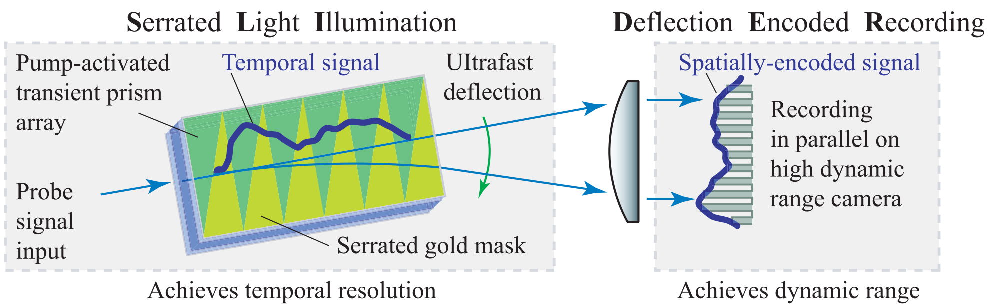

Fig. 1. The SLIDER concept is based on optically-induced deflection of an optical signal propagating in a planar waveguide. The deflection is caused by an array of transient prisms that are simultaneously induced by a pump beam applied perpendicular to the guide through a serrated mask. The prisms remain active for the duration of the beam sweep. Signal time of flight through the device ensures a linear mapping of time to angle. A focusing lens maps angle to space, where a conventional camera records the energy in each time slot with high dynamic range.

IV. Experimental Demonstration

We fabricated a SLIDER deflector from a planar waveguide with a 0.6 μm undoped GaAs core and a 24% AlGaAs cladding. A gold serrated mask with 60 μm pitch and 1.2 cm lateral width was deposited above the top cladding. Experiments were performed with an 800 nm Ti:Sapph oscillator regeneratively amplified to 1 mJ. The SLIDER pump used 160 μJ in a 0.15 ps pulse. A refractive shaper flattened the pump beam to yield a uniform fluence of 65 $\mu J/cm^2$ over a 1.2 cm square. The remaining energy pumped an optical parametric amplifier generating a 1900 nm idler that is subsequently doubled to 950 nm and filtered to 1.4 nm FWHM. A test signal was generated by a Gires-Tournois interferometer (GTI), yielding a ring-down pattern of $\sim$1 ps pulses separated by 10 ps intervals. At the waveguide output, cylindrical lenses mapped the swept beam onto a camera triggered to record single-shot traces. Figure 2 displays a recorded ring-down pattern from a single row of pixels.

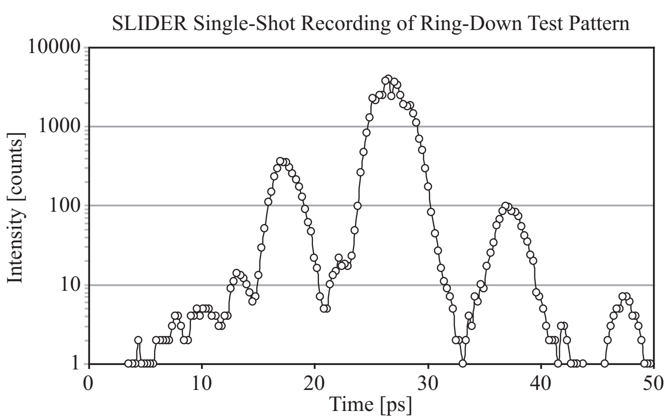

Fig. 2. SLIDER recorded trace of a GTI ring-down signal with $\sim$1 ps impulses. The GTI mirror spacing was used to calibrate the mapping of space to time. Sub 3 ps temporal resolution (FWHM) is maintained over a record of 40 ps. Dynamic range was limited by the camera ($<$ 3000:1).

V. Conclusion

We have demonstrated a novel beam deflector that can, in conjunction with a camera, record single-shot optical waveforms with sub 3 ps resolution. The technique is potentially scalable to high dynamic range across hundreds of picoseconds. Multichannel operation could be obtained by stacking guiding layers vertically or by multiplexing signals entering a single layer at different angles. Phase sensitive recording can be achieved through heterodyning and spectrogram recording can be achieved by inserting a grating prior to the camera. Finally, the use of rad-optic conversion schemes[6] allows for the transcoding of ultrafast x-ray transients onto an optical carrier for subsequent recording in a SLIDER device.

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